

CONTRACT REPORT ARBRL-CR-00471

MUZZLE FLOW IN THE PRESENCE OF AN
ANTI-RECOIL PLATE: EXPLORATORY STUDY

Prepared by

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strated that a major reshaping of the code has to be undertaken in order to provide efficient computational grids.

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MUZZLE FLOW IN THE PRESENCE OF AN ANTI-RECOIL PLATE

Exploratory study

I. Introduction

We have explored the possibility of determining the effect of an anti-recoil plate on the muzzle blast flow, by a numerical analysis. To reduce the problem to its essential elements, we assumed that the blast was produced by a piston moving inside the gun, as it is in the precursor flow, and we did not consider the presence of the projectile and of hot gases in its back. The anti-recoil plate was considered as a rigid, unpierced wall, extending to infinity and normal to the gun axis. Initial conditions were taken as in our previous calculations of precursor flows (Ref. 1). We assume that the reader is familiar with Ref. 1 and we use the same nomenclature used therein.

The analysis, as detailed below, intended to examine whether it would be possible to use the existing code for the calculation of precursor flows, with some minor modifications.

II. First attempt

A first attempt was made using the original code for the numerical analysis of the precursor flow in the absence of the projectile, with just one minor modification.

The original program computes the flow between the gun and the precursor wave, considered as the outer boundary of the region to be computed. Boundary conditions on the precursor wave are the Rankine-Hugoniot conditions for a shock proceeding into a gas at rest. The region external to the gun barrel is mapped

onto the region external to the unit circle in an auxiliary plane. The mapping is conformal; points in the physical plane are defined by a complex variable, $z = x + iy$, and points in the auxiliary plane are defined by a complex variable, $\zeta = \rho e^{i\theta}$. The two complex variables are related by the analytic transformation:

$$z = (r_0/\pi)[(z_1^2 - 1/z_1^2)/2 - \log z_1^2 - i\pi] \quad (1)$$

$$z_1 + 1/z_1 = 2B(\zeta + 1/\zeta)$$

where r_0 is the outer radius of the barrel, and B is determined to assure correspondence between $\zeta=1$ and $z=-i$. Lines of constant ρ and constant θ are mapped onto the grid shown in Fig. 1. The image of the precursor wave on the ζ -plane is defined by a function, $\rho=c(\theta,t)$ and it turns out to be an almost perfect circle. Nevertheless, a normalization of coordinates along each $\theta = \text{constant}$ line is necessary, in order to maintain evenly spaced mesh points along such lines in the computational space. In practice, thus, the grid in the physical plane is not perfectly orthogonal, although its departure from orthogonality is not conspicuous. Anytime a non-orthogonal mesh is used, additional terms appear in the equations of motion, which impair the accuracy of the calculation. In the precursor flow analysis, however, such effects are minimal. Inserting a plate, normal to the gun axis, at a given distance from the muzzle, simply means that all points on the outer boundary in the ζ -plane which fall behind the image of the plate must be replaced by boundary points on the image of the plate itself, corresponding to the same values of θ . At such points, not the Rankine-Hugoniot conditions but the well-known boundary conditions on a rigid wall will be applied. In principle, no other modifications to the code are necessary, since the distribution of interior points follows automatically as a consequence of normalizing the computational coordinate X between the muzzle and the outer boundary, whichever is.

In practice, one finds that the grid, so defined, is not suited for the calculation and will generate catastrophic inaccuracies.

Our statement is supported and clarified by Figs. 2, 3 and 4, which show the computational grid in the physical space at three successive instants of time. The progressive degeneration

of the grid, produced by the different normalization between precursor wave points and wall points, is evident. While at most of the points the grid is almost orthogonal, the departure from orthogonality is too strong to be acceptable along at least three $Y=\text{constant}$ lines. There, the calculation rapidly degenerates and stops.

Nevertheless, the code shows its capacity to describe the flow, once a proper grid is adopted. In fact, one can see in Fig. 4 two lines representing two imbedded shocks which result as a consequence of the impact of the precursor flow on the plate. The fact that the shock appears to be divided in two pieces is a consequence of the assumption, implicit in the code, that the imbedded shocks are always in the general direction of $\rho=\text{constant}$ lines; whenever a portion of a shock tends to lie along $\theta=\text{constant}$ lines, as it would occur between the two shocks of Fig. 4 if one joined them, that portion is automatically cut off.

From the experiments described above, we concluded:

- 1) A more efficient method of grid generation is needed, and
- 2) A more general analysis of imbedded shocks is needed.

III. Second attempt

A second attempt was then made, after modifying the computational grid. The computational region corresponding to the original grid is a rectangle, limited by the lines: $X=0$ (barrel mouth), $X=1$ (precursor wave), $Y=0$ (barrel wall), and $Y=\pi/2$ (centerline). In this attempt, the centerline of the flow (the axis of the gun) and the plate are taken as two parts of the same boundary line in the (X,Y) -plane (the $Y=\pi/2$ line). To this effect, the mapping of the z -plane onto the ζ -plane is modified as follows. The variable z of Eqs. (22) of Ref. 1 (repeated here as Eqs. (1)) is renamed z_3 ; to obtain z , the following additional sequence of transformations is used:

Second attempt

$$z_4 = - \frac{z_3(r_0^2 + 4x_w^2)}{z_3 - \kappa} + x_w^2$$

$$z_5 = (z_4)^{1/2}, \quad z = x_w - z_5$$

where x_w is the distance between the muzzle and the plate, and κ is a constant, determined in such a way that the imaginary part of the complex coordinate of the inner lip of the muzzle in the z_3 -plane is $-i$. The successive transformations are described by Fig. 5.

The scope of the transformation between the z -plane and the z_4 -plane is to align the plate (AB) with the centerline (FA). Consequently, the FD line and the DE line become parabolas. Assuming that the arc FCD on the z_4 -plane can be considered as a circular arc, the bilinear transformation between the z_4 -plane and the z_3 -plane straightens up the FCD line again, without changing the shape of the FAB straight line. Finally, the original transformation between the z_3 -plane and the ζ -plane produces a computational region in the ζ -plane which is very similar to the circular sector of Ref. 1, except that the CDE line is no longer a straight line. Consequently, a more complicated definition of stretching functions has to be used, since the value of θ on the CDE boundary is now, for each point, a function of ρ and t ; note, indeed, that the computational region expands as the precursor shock moves out, so that the points to be evaluated on the CDE boundary move in time along such line.

Recoding of a part of the program was then necessary since now both X and Y are functions of ρ , θ and t , whereas in (49), Ref. 1, Y was a function of θ alone.

In the first phase of the evolution, the grid so obtained looks promising and efficient (Fig. 6). Not the same can be said of the shock pattern. In fact, the most important shock, the one which originates as a consequence of the impact of the flow on the plate, runs now in the general direction of $\theta = \text{constant}$ lines. The program, as originally written, is unable to fit it, as we can see from Fig. 7, drawn at a further stage.

IV. Third attempt

The code was then modified, reversing the role played by the coordinates in the calculation of the shock; this, of course, entails more than a simple switch of symbols, since the dimensions of ρ and θ are different, and the stretching functions for X and Y are different too. In Fig. 8, we see that the shock reflected by the wall does now appear, while the other shocks are replaced by sharp transitions.

Unfortunately a new problem arises, as shown in Fig. 9. The lines here are $\theta = \text{constant}$ coordinate lines. They tend to cluster around a point on the plate, with two catastrophic effects: the reduction of the time step size to vanishingly small values, and a loss of resolution in the upper part of the figure (which, as is evident in Fig. 9, may even cause overlapping of mesh lines).

The reason for it is that the point at infinity in the z_4 -plane maps on the point $z_3 = K$ (denoted by K in Fig. 5) in the z_3 -plane. The semi-infinite line issuing from D , which is the outer wall of the gun, is then mapped onto the circular arc, DK . When the precursor shock moves out with a quasi-circular shape in the physical plane, its image in the ζ -plane is, instead, quasi-rectangular (Fig. 10). This is due to the fact that, regardless of the motion of the shock alongside the barrel, its image cannot move any farther than point K in the ζ -plane.

A brief, but formally complicated, attempt was made to correct the defect mentioned above, by using different values of θ for different values of X , on any $Y = \text{constant}$ line. An example of the grid is given in Fig. 11, and a plot of isobars appears in Fig. 12, definitively one of the best obtained so far. We intended to use it in order to advance, at least, to a stage where the reflected shock had moved towards the side of the barrel, although we do not approve of such a choice of stretching. Indeed, it defies the purpose of using conformal mappings as much as possible; conformal mappings should be used to provide the

basic relations between pairs of coordinates, whereas stretchings should be limited to functions of a single variable, essentially. In addition, such a definition of stretching is very complicated, in contradiction with the principle that most of the complications should be kept in the conformal mappings.

In any event, even the new correction did not serve the purpose, because soon the determination of values in the vicinity of K exceeded the limits of accuracy of the computer. The computation, which had started with promising results, had to be interrupted shortly after the stage shown in Fig. 12.

V. Conclusions and recommendations

It is clear that the gasdynamical portion of our codes is working well, and that such codes can provide reliable results. Comparisons of our computed flow patterns with shadowgraphs of actual experiments, provided by BRL, are very satisfactory.

It is also clear, however, that a major reshaping of the code has to be undertaken, in order to provide efficient computational grids.

We propose to examine the possibility of using two grids for two different regions, with a seam as shown in Fig. 13. The upper grid, for the analysis of region ABCD, is the same as the one described in the second attempt. As soon as the precursor shock has crossed the BC line completely (at time $t=t_0$, say), the perturbed flow field below BC would be redefined on the lower grid.

The latter can be generated by the following mapping function:

$$z = t + \frac{1}{2} \log \frac{1-t}{1+t} \quad , \quad t = [(A\zeta+B)/(\zeta+A)]^{1/2}$$

with A and B properly defined. Typical grid lines for this map-

Conclusions and recommendations

ping are shown in Fig. 14.

We would also perform the calculation with an improved treatment of shock waves, to account for shocks lying in any direction with respect to the mesh. Finally, we would speed up the calculation by eliminating most of the viscous code, according to our current computational philosophy.

VI. References

1. Moretti, G., A numerical analysis of muzzle blast precursor flow, POLY M/AE Rep. No. 80-10, 1980.

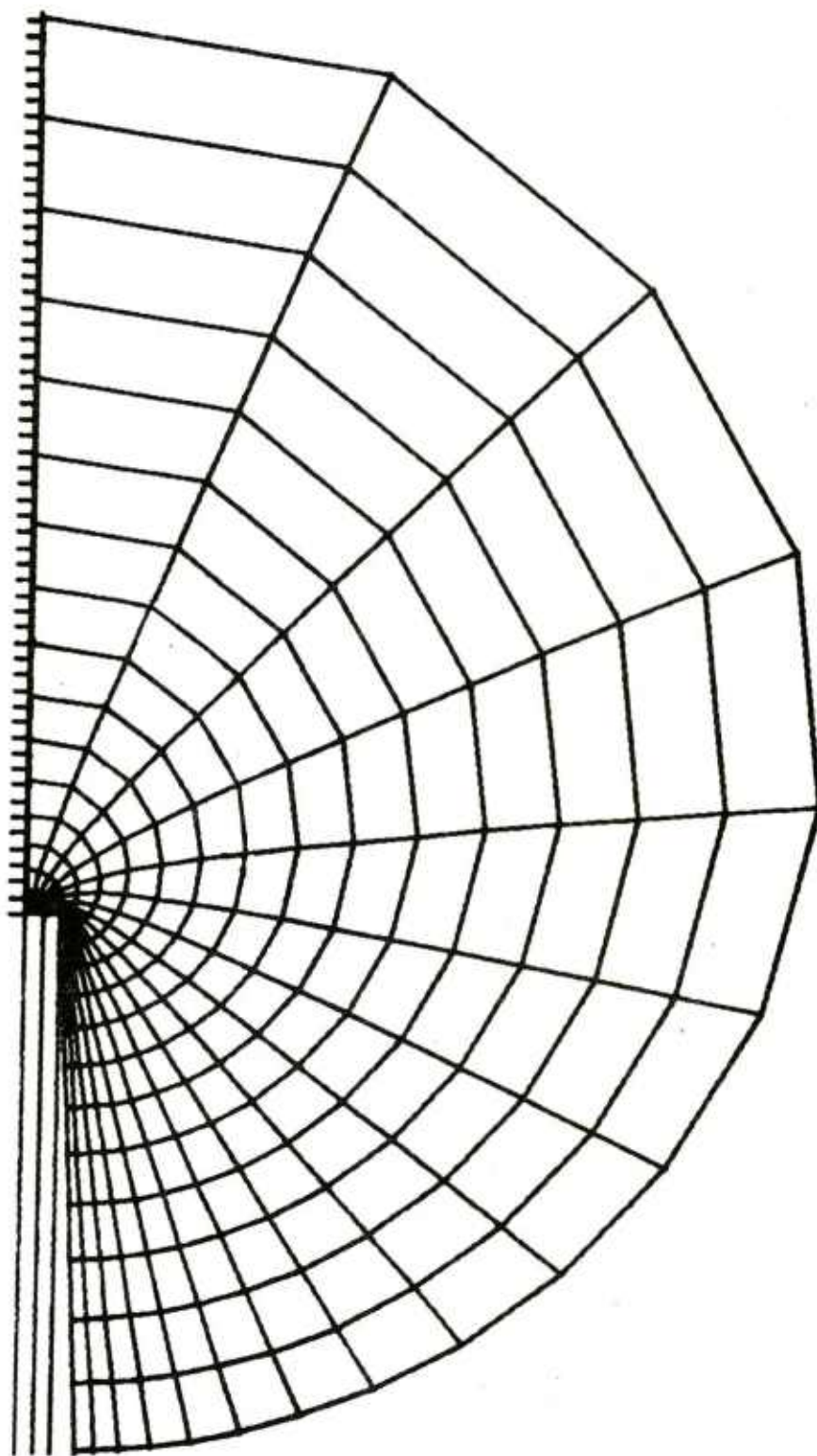


Figure 1. Initial Mapping Grid

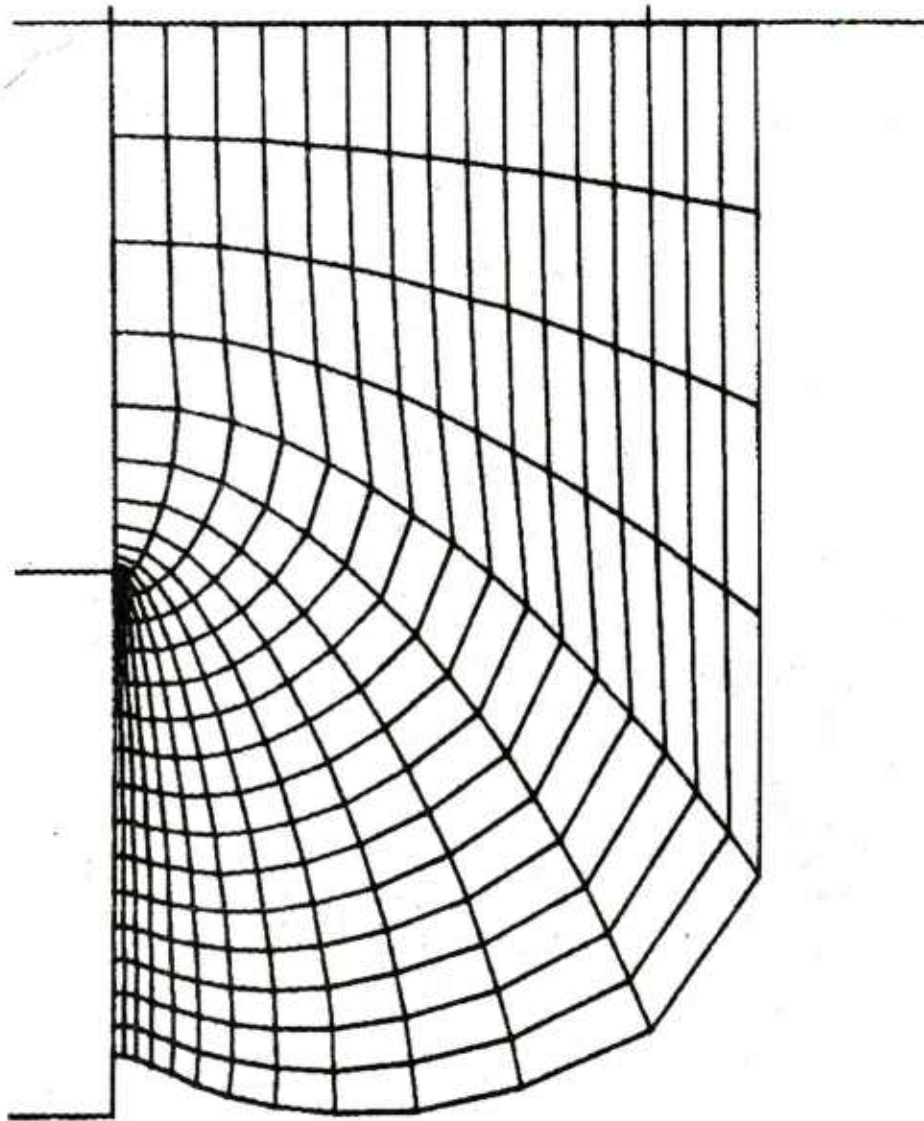


Figure 2. Grid Distortion - Early Time

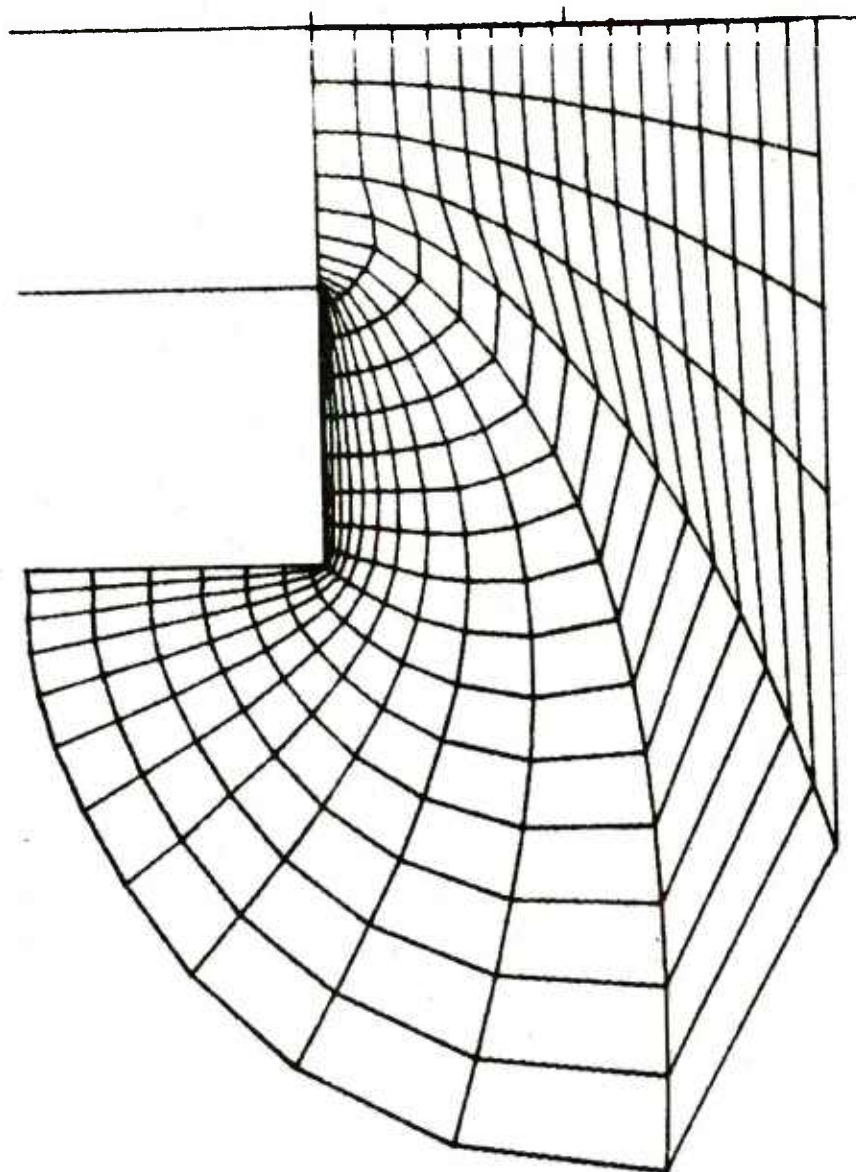


Figure 3. Grid Distortion - Median Time

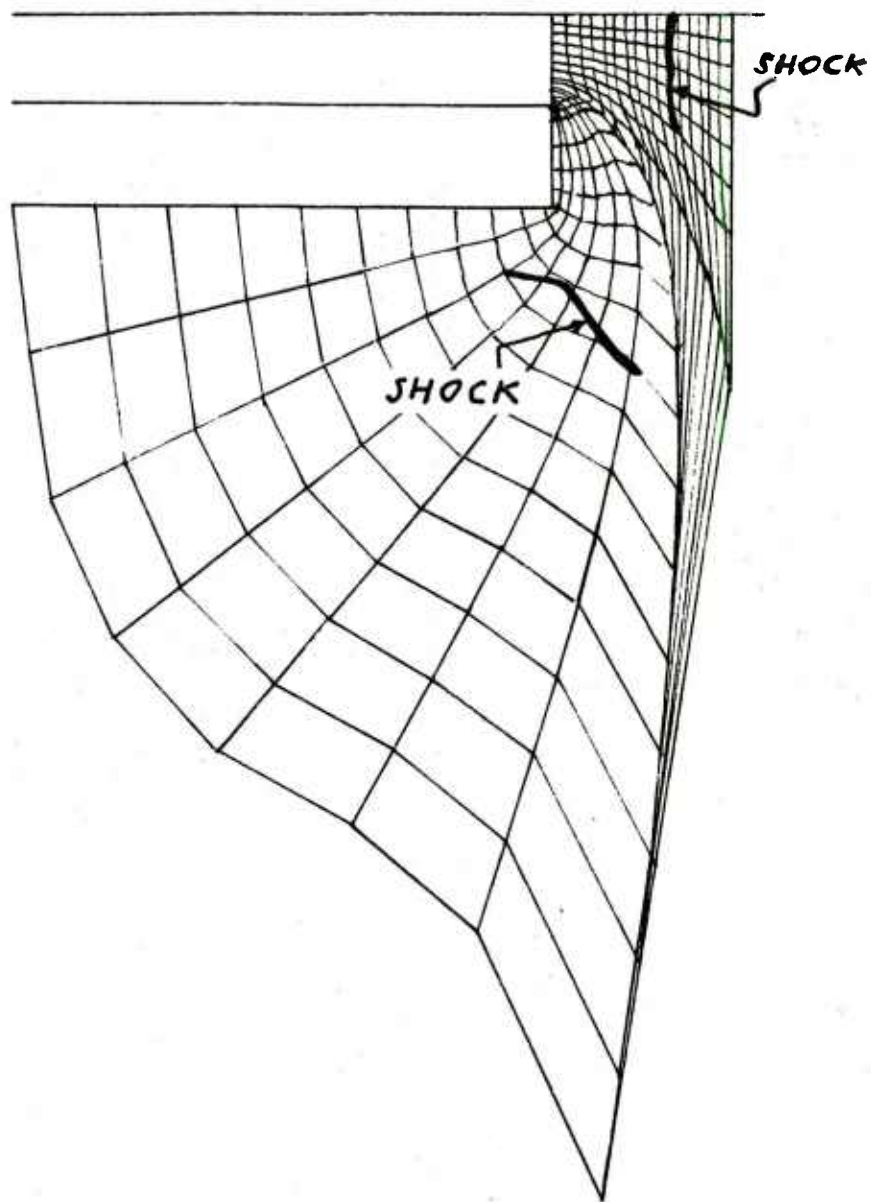


Figure 4. Grid Distortion - Late Time

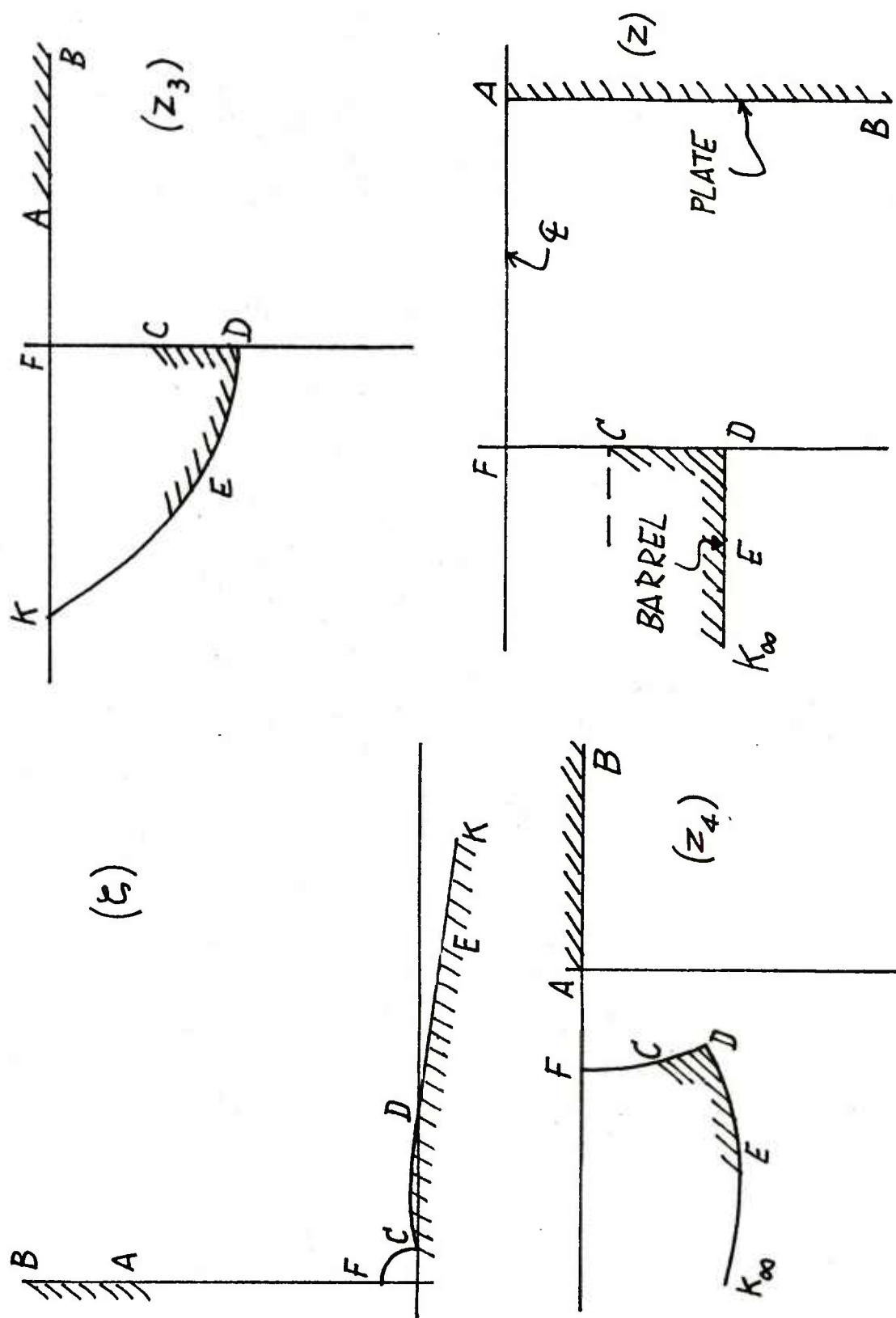


Figure 5. Successive Transformations

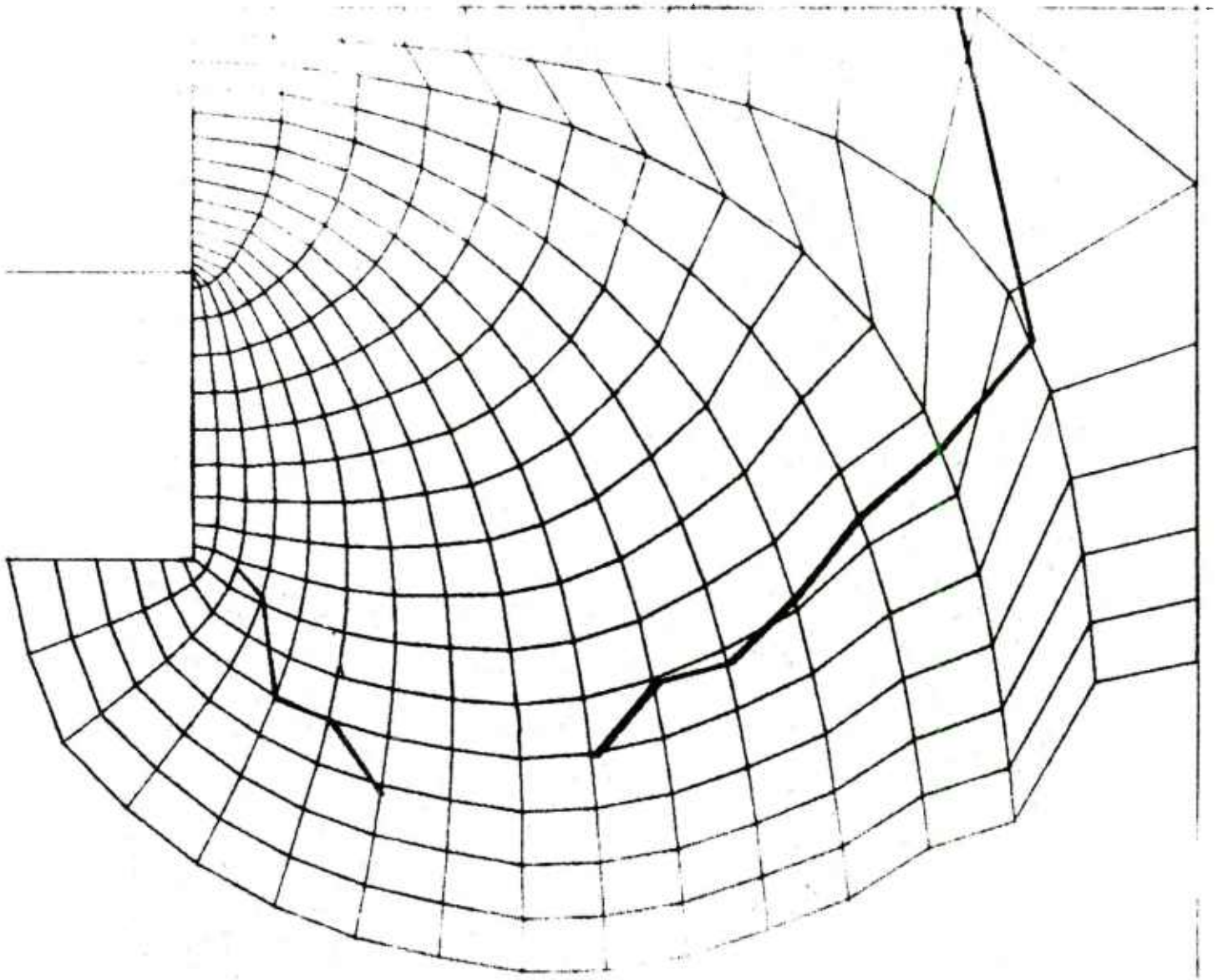


Figure 6. Second Grid Distortion - Early Time

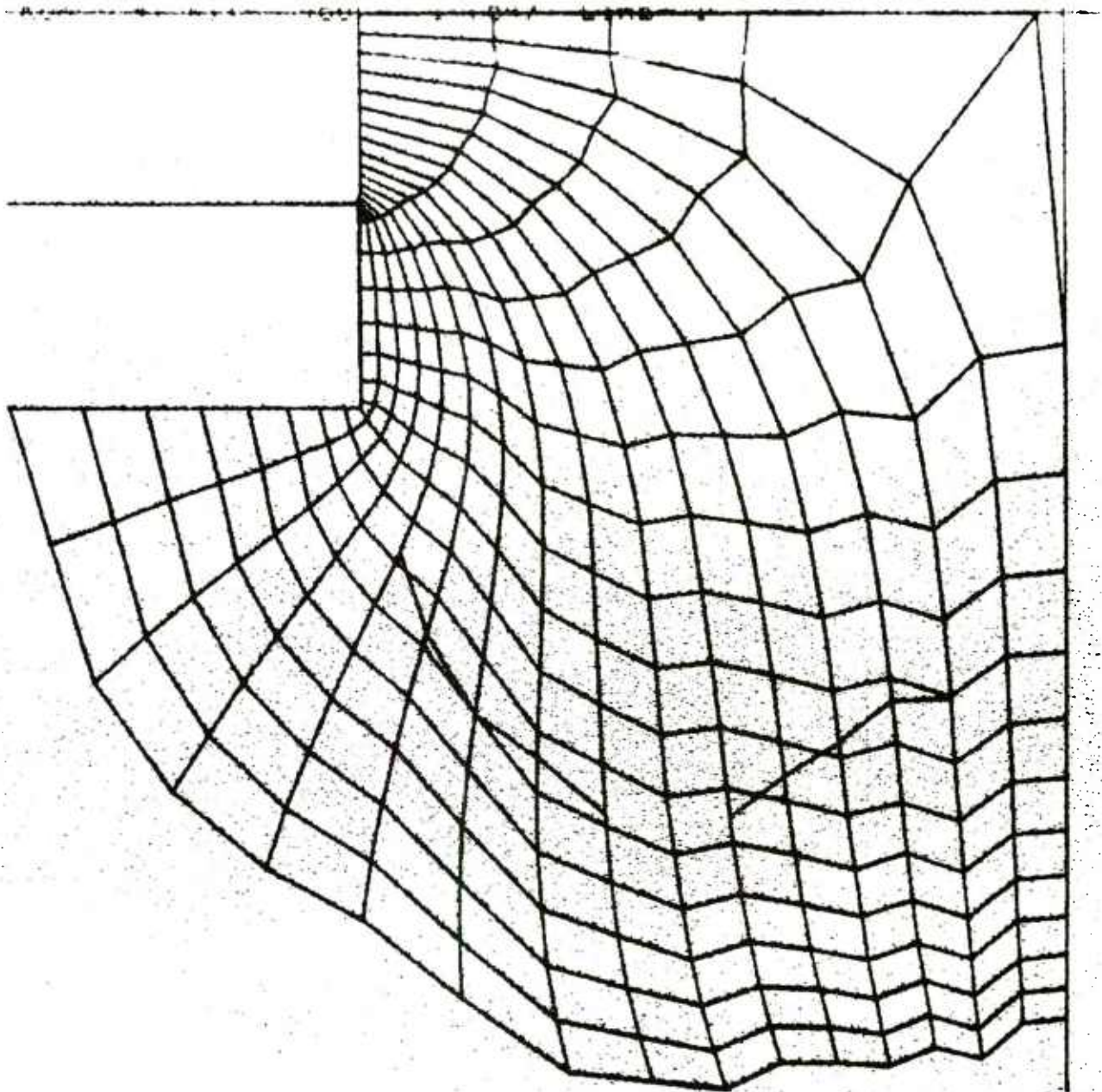


Figure 7. Second Grid Distortion

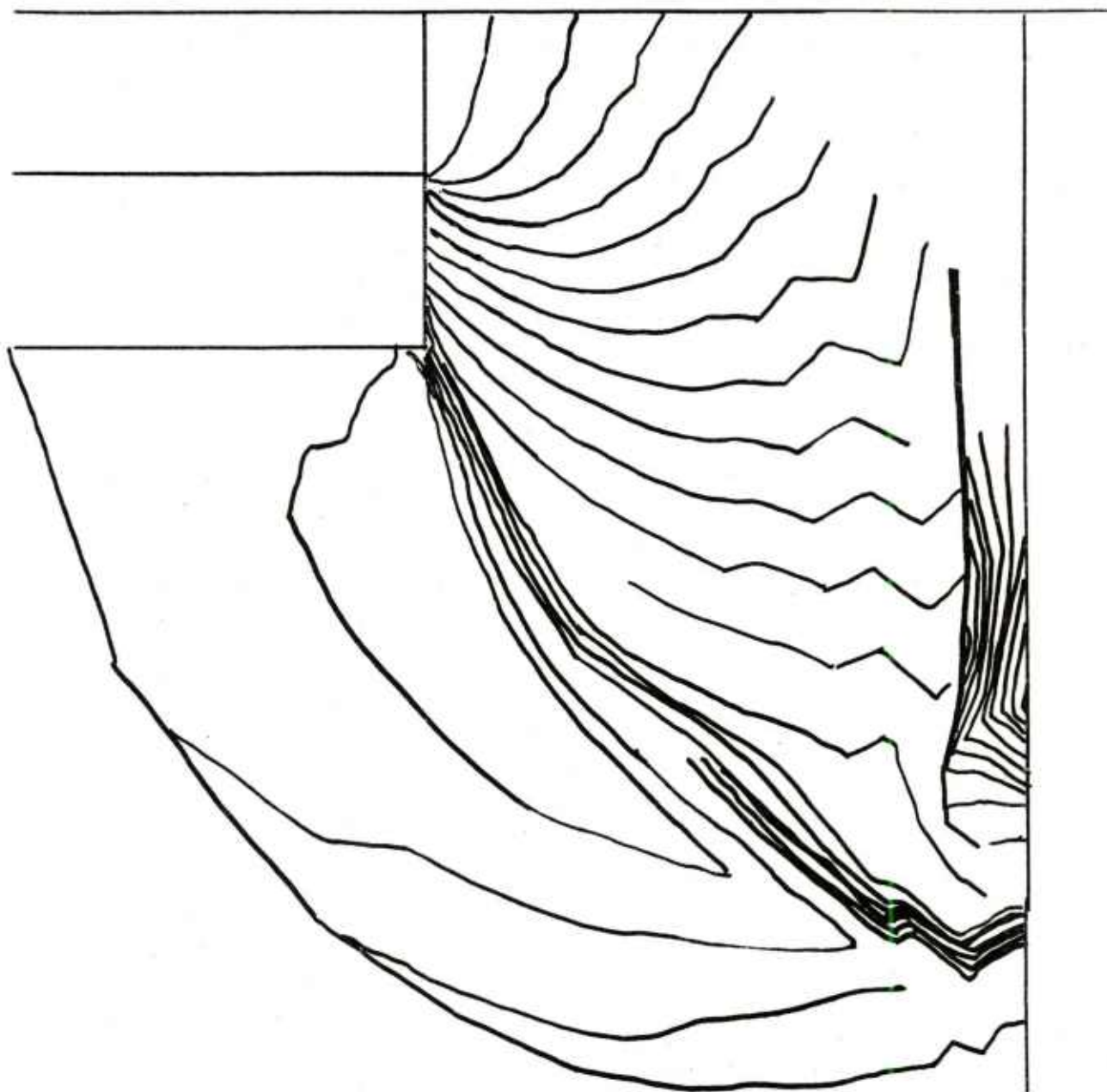


Figure 8. Shock Structure Predicted with Third Grid

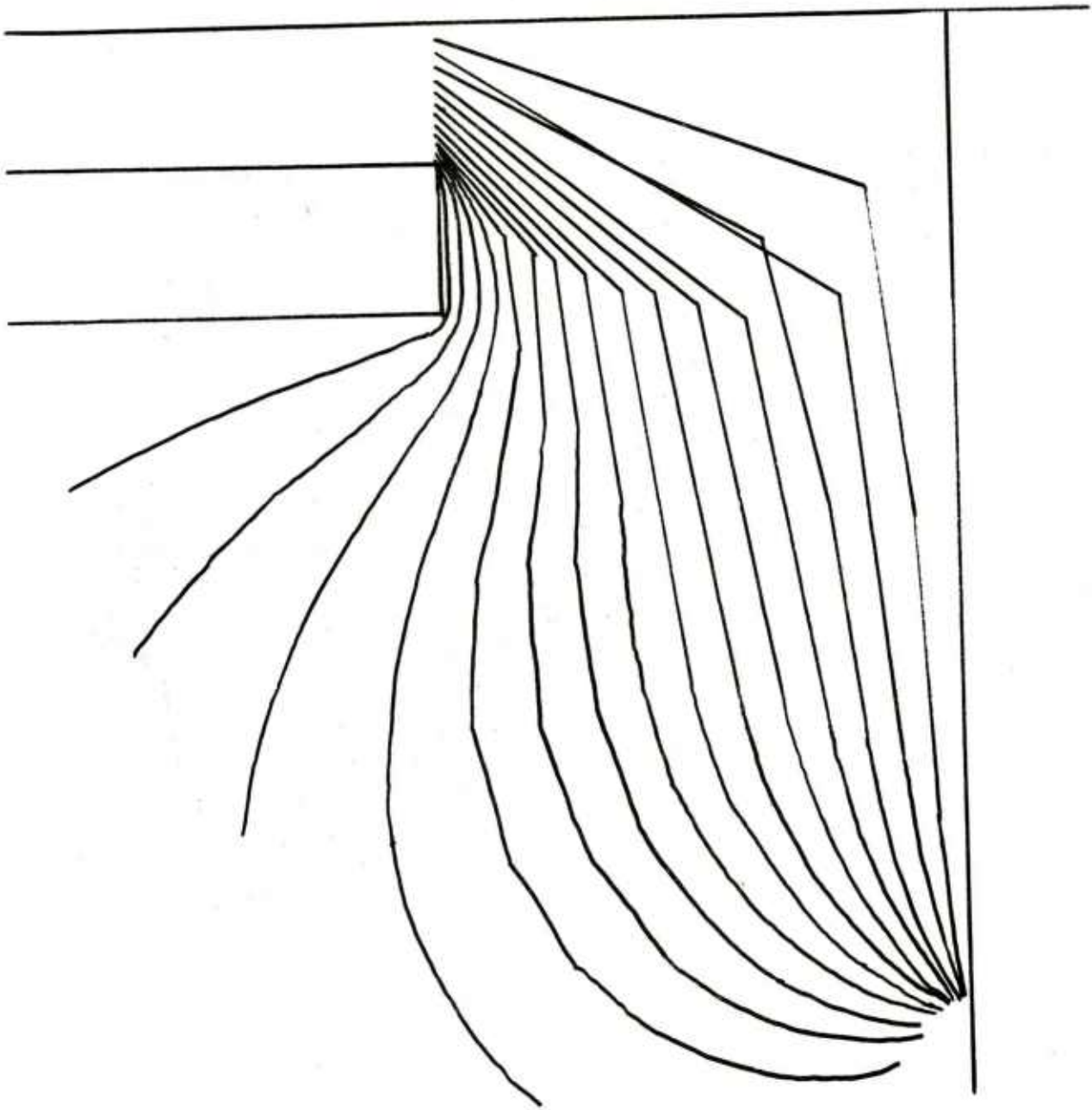


Figure 9. $\theta = \text{Constant}$ Coordinate Lines, Third Grid

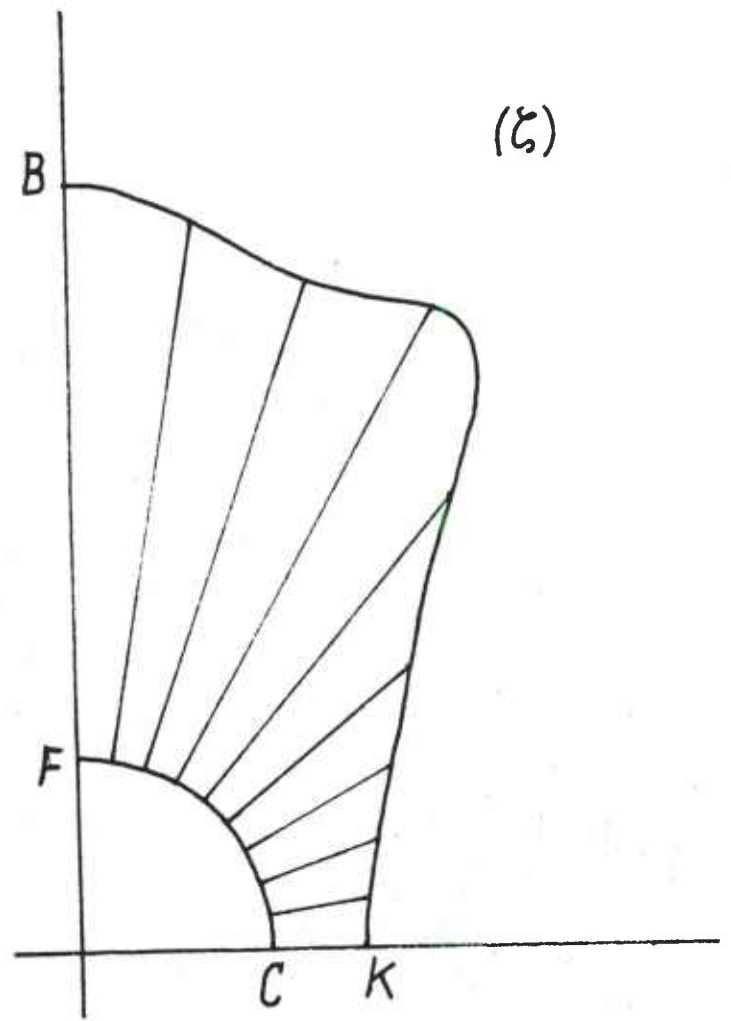


Figure 10. Precursor Image in ξ - Plane

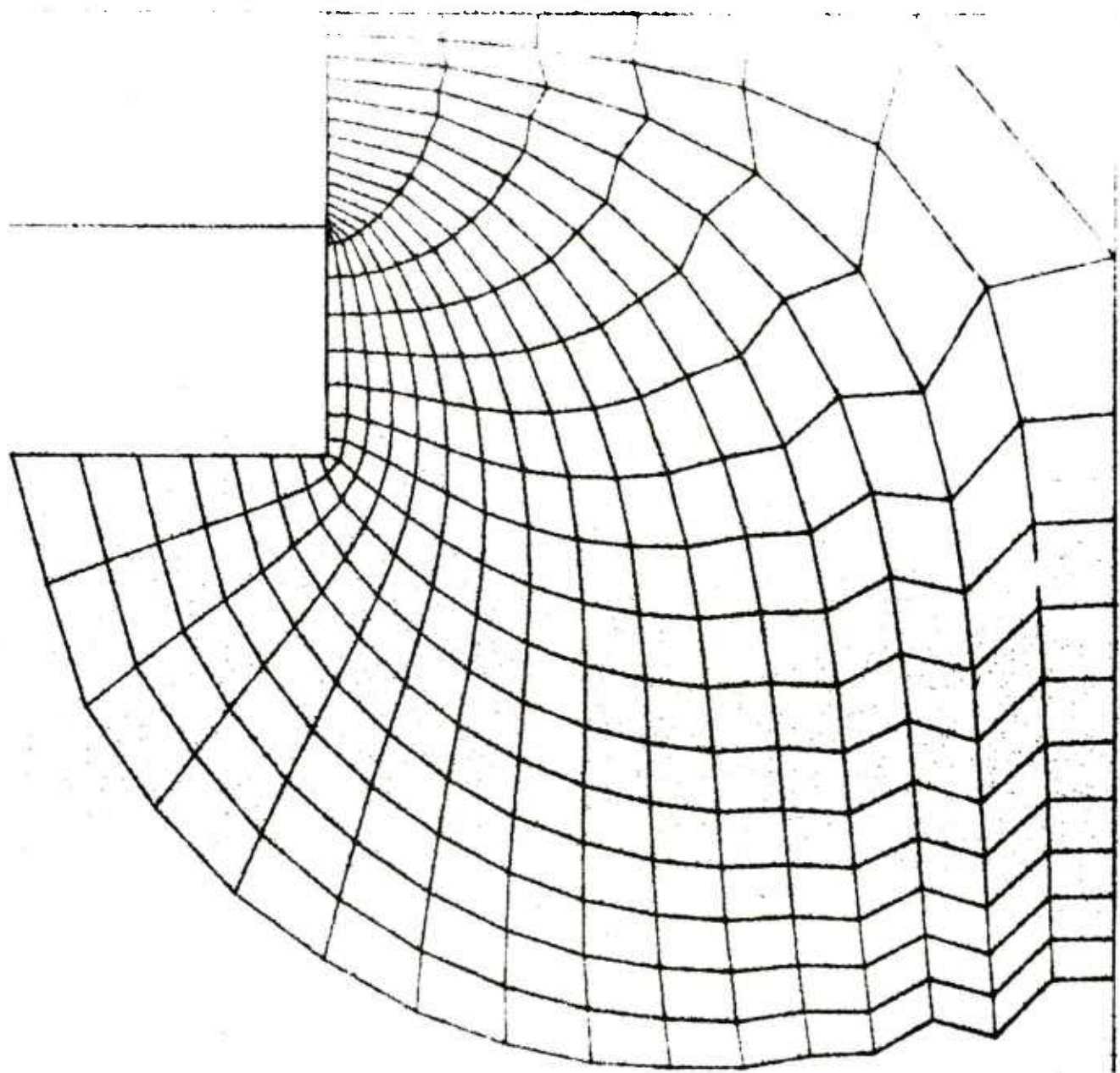


Figure 11. Third Grid

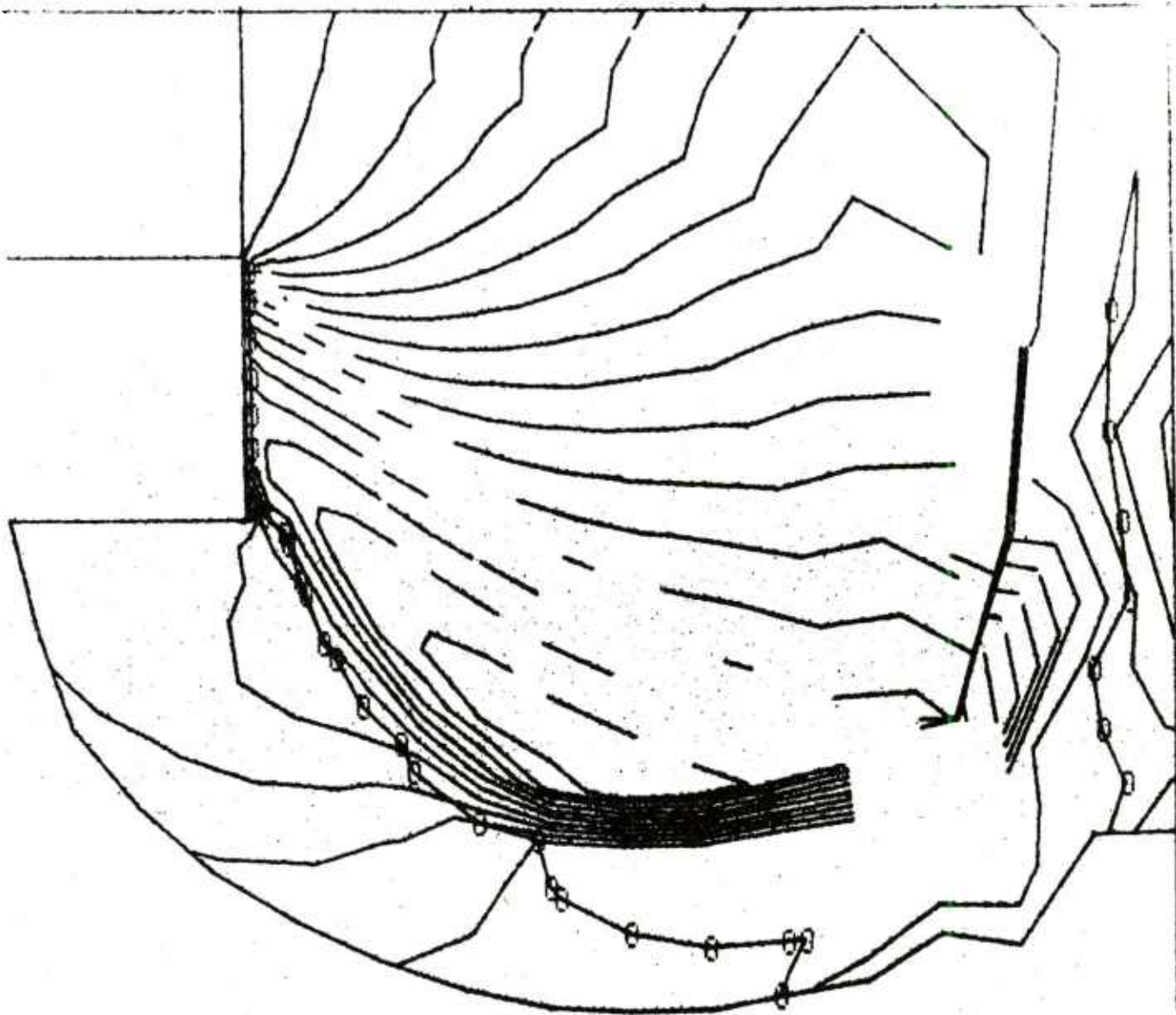


Figure 12. Isobars Computed Using Third Grid

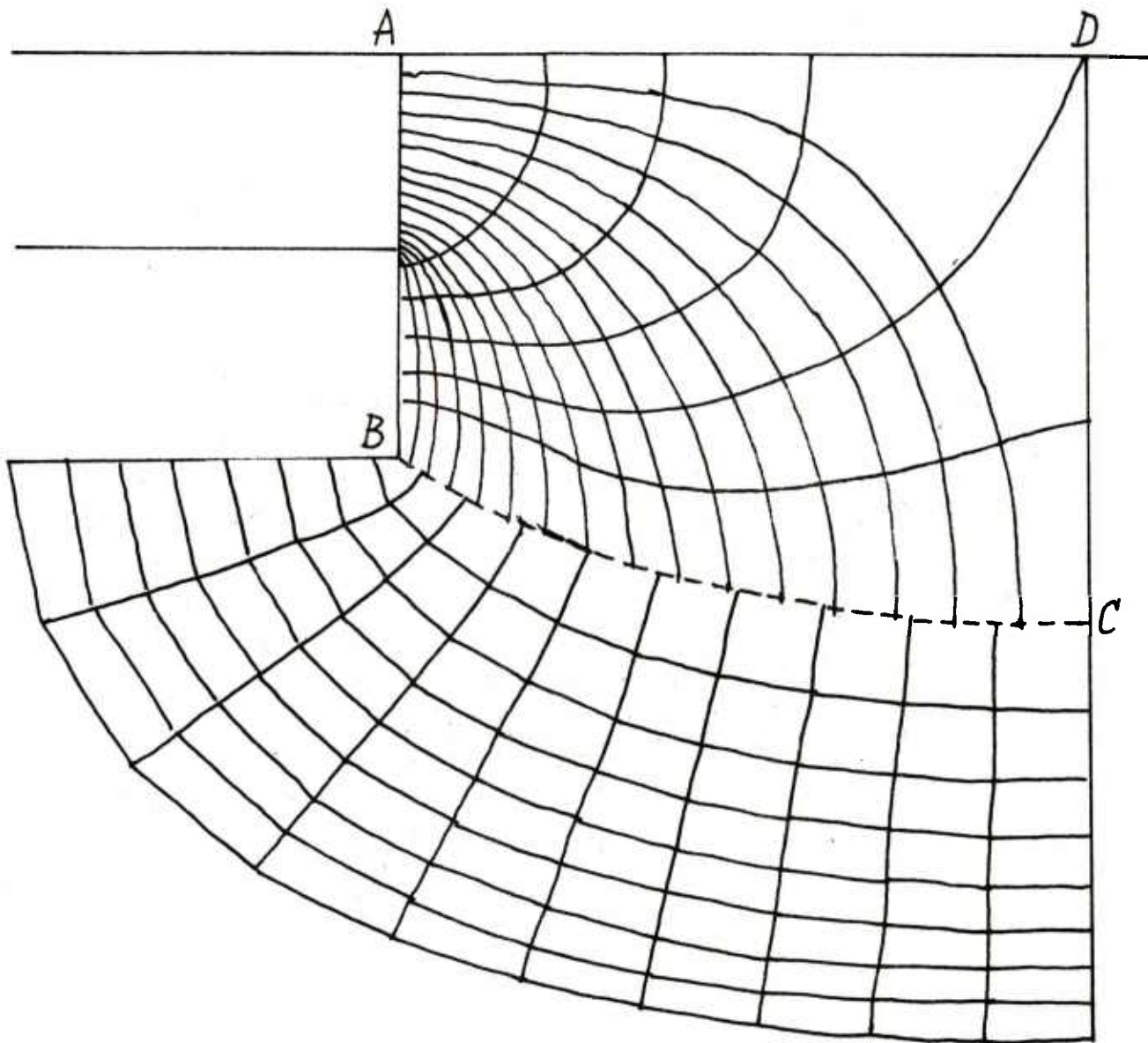


Figure 13. Proposed Double Grid Scheme

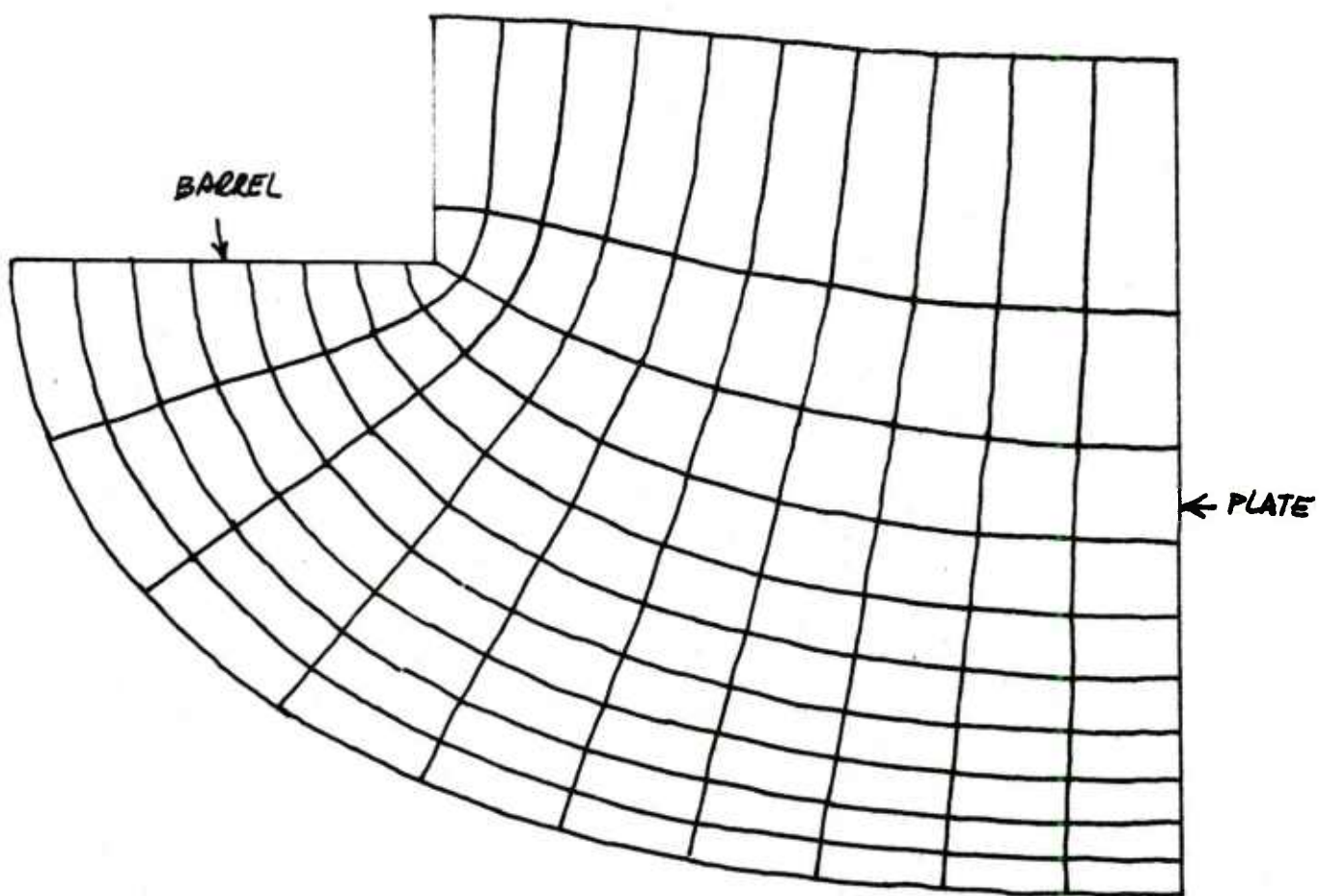


Figure 14. Grid Lines

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